410 Rec'd PCT/PTO 22 MAY 2000

FORM PTO-1390 (Modified) (REV 10-95) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER
9847-0048-6X PCT pct

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR
09/554905

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/SE98/02161	**NOVEMBER 27, 1998**	**NOVEMBER 27, 1997**

TITLE OF INVENTION
A METHOD AND A SYSTEM FOR SPEED CONTROL OF A ROTATING ELECTRICAL MACHINE WITH FLUX COMPOSED OF TWO QUANTITIES

APPLICANT(S) FOR DO/EO/US
Erland SORENSEN

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☒ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210).
8. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☐ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 13 to 18 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment doeument for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
    A **SECOND** or **SUBSEQUENT** preliminary amendment.
16. ☒ A substitute specification.
17. ☐ A change of power of attorney and/or address letter.
18. ☐ Certificate of Mailing by Express Mail
19. ☒ Other items or information:

Request for Consideration of Documents Cited in International Search Report
Notice of Priority
Form PTO 1449
List of Related Cases
Marked-up Specification
Response to Petition Under 37 CFR 1.182

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U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 09/554905	INTERNATIONAL APPLICATION PCT/SE98/02161	9847-0048-6X PCT

20. The following fees are submitted:.

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

		CALCULATIONS	PTO USE ONLY
☐ Search Report has been prepared by the EPO or JPO	$840.00		
☐ International preliminary examination fee paid to USPTO (37 CFR 1.482)	$670.00		
☐ No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2))	$760.00		
☒ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2) paid to USPTO	$970.00		
☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4)	$96.00		
ENTER APPROPRIATE BASIC FEE AMOUNT =		$970.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).		$130.00	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	35 - 20 =	15	x $18.00	$270.00	
Independent claims	4 - 3 =	1	x $78.00	$78.00	
Multiple Dependent Claims **(check if applicable).**			☐	$0.00	
	TOTAL OF ABOVE CALCULATIONS		=	$1,448.00	
Reduction of 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28) **(check if applicable).**			☐	$0.00	
	SUBTOTAL		=	$1,448.00	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)).			+	$0.00	
	TOTAL NATIONAL FEE		=	$1,448.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).**			☐	$0.00	
	TOTAL FEES ENCLOSED		=	$1,448.00	
				Amount to be: refunded	$
				charged	$

☒ A check in the amount of **$1,448.00** to cover the above fees is enclosed.

☐ Please charge my Deposit Account No. in the amount of to cover the above fees. A duplicate copy of this sheet is enclosed.

☒ The Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. **15-0030** A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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REGISTRATION NUMBER 30,996

SIGNATURE

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25,599
REGISTRATION NUMBER

May 22, 2000
DATE

09/554905

526 Rec'd PCT/PTO 22 MAY 2000

9847-0048-6XPCT
ENKEL 8335

IN THE UNITED STATES PATENT & TRADEMARK OFFICE

IN RE APPLICATION OF:	:
SORENSEN, ERLAND	: ATTN: APPLICATION DIVISION
SERIAL NO: NEW APPLICATION (BASED ON PCT SE98/02161)	:
FILED: HEREWITH	:
FOR: A METHOD AND A SYSTEM FOR SPEED CONTROL OF A ROTATING...	:

PRELIMINARY AMENDMENT

ASSISTANT COMMISSIONER OF PATENTS
WASHINGTON, DC 20231

Prior to examination on the merits, please amend the above-identified application as follows:

IN THE CLAIMS

Please cancel Claims 1-32 without prejudice or disclaimer and add Claims 33-67 as follows:

--33. A system configured to adapt a speed of a rotating electric machine in said system, comprising:

a stator and air gap, in which flux is generated, said flux being composed of at least two vectorial quantities for said rotating electric machine during an operation of said rotating electric machine; and

at least two electric windings that generate said flux, wherein said at least two electric windings including

an electric conductor,

a first semiconducting layer configured to surround said electric conductor,

an insulating layer configured to surround said first semiconducting layer, and

a second semiconducting layer configured to surround said insulating layer,

wherein said rotating electric machine being configured to be directly connected to at least one of a distribution network and a transmission network.

34. The system according to claim 33, wherein a potential of said first semiconducting layer being substantially equal to a potential of said electric conductor.

35. The system according to claim 33, wherein said second semiconducting layer being configured to form a substantially equipotential surface surrounding said electric conductor.

36. The system according to claim 35, wherein said second semiconducting layer being connected to a node at a predetermined potential.

37. The system according to claim 36, wherein said predetermined potential being a ground potential.

38. The system according to claim 33, wherein at least two adjacent layers of said at least two electric windings of said rotating electric machine having a substantially identical coefficient of thermal expansion.

39. The system according to claim 33, wherein said electric conductor further comprises a plurality of strands and at least two strands of said plurality of strands being in electric contact.

40. The system according to claim 33, wherein said first semiconducting layer, said insulating layer, and said second semiconducting layer being secured to at least one adjacent layer selected from a set of said first semiconducting layer, said second insulating layer, and said second semiconducting layer along a substantially whole contact surface.

41. A system configured to adapt a speed of a rotating electric machine in said system, wherein said rotating electric machine being directly connected to at least one of a distribution network and a transmission network, said system comprising:

a stator and air gap, in which flux is generated, said flux having at least two vectorial quantities; and

at least two electric windings, including

a high-voltage cable, including,

a current-carrying conductor comprised of a plurality of strands,

a first semiconducting layer arranged around said current-carrying conductor,

an insulating layer of a solid insulating material arranged around said first semiconducting layer, and

a second semiconducting layer arranged around the insulating layer.

42. The system according to claim 41, wherein said high-voltage cable being flexible.

43. The system according to claim 42, wherein said first semiconducting layer, said insulating layer, and said second semiconducting layer being arranged to adhere to at least one other layer selected from a set of said first semiconducting layer, said insulating layer, and said second semiconducting layer when said high-voltage cable is bent.

44. The system according to claim 41, wherein said rotating electric machine comprises:

an extra winding arranged on a stator of said rotating electric machine; and

a magnetization apparatus connected to said rotating electric machine;

wherein a first flux vector of said at least two vectorial quantities being generated via said extra winding and said magnetization apparatus and a second flux vector of said at least two vectorial quantities being generated via said at least two electric windings.

45. The system according to claim 44, wherein said magnetization apparatus being a first frequency converter.

46. The system according to claim 45, wherein said system further comprises an auxiliary feeder connected to said first frequency converter and said rotating electric machine.

47. The system according to claim 46, wherein:

said rotating electric machine being an asynchronous rotor; and

said auxiliary feeder comprising a stator winding and a permanent magnet rotor connected to said asynchronous rotor.

48. The system according to claim 46, further comprising:

a transformer connected to said first frequency converter and said auxiliary feeder, said transformer being connected to a distribution busbar via a first circuit breaker; and

a second frequency converter connected to said transformer and connected to said distribution busbar via a second circuit breaker.

49. The system according to claim 33, wherein:

said at least two electric windings being flexible; and

said first semiconducting layer, said insulating layer, and said second semiconducting layer making contact with at least one neighboring layer selected from a set of said first semiconducting layer, said insulating layer, and said second semiconducting layer.

50. The system according to claim 49, wherein said first semiconducting layer, said insulating layer, and said second semiconducting layer being made of a plurality of materials with a plurality of elasticities and a plurality of coefficients of thermal expansion configured to absorb volume changes of said first semiconducting layer, said insulating layer, and said second semiconducting layer caused by a temperature variation during an operation such that said first semiconducting layer, said insulating layer, and said second semiconducting layer remain in contact with one another over an operational temperature range.

51. The system according to claim 50, wherein the plurality of materials in said first semiconducting layer, said insulating layer, and said second semiconducting layer having a plurality of high elasticities.

52. The system according to claim 50, wherein said first semiconducting layer and said second semiconducting layer being configured to form substantially equipotential surfaces.

53. A method for speed control of a rotating electric machine configured to be directly connected to a distribution network, comprising:

generating at least two vectorial quantities which constitute a resultant flux of said rotating electric machine during an operation, wherein said rotating electric machine having at least two electric windings, each winding including

at least one electric conductor,

a first semiconducting layer arranged surrounding said electric conductor,

an insulating layer surrounding said first semiconducting layer, and

a second semiconducting layer arranged surrounding said insulating layer.

54. A method for speed control of a rotating electric machine configured to be directly connected to a distribution network and having at least two electric windings formed from a high-voltage cable including at least one current-carrying conductor wherein said at least one current-carrying conductor exhibits a plurality of strands, a first semiconducting layer arranged around said at least one current-carrying conductor, an insulating layer made of a solid insulating material arranged around said first semiconducting layer, and a second semiconducting layer arranged around said insulating layer, said method comprising the step of:

generating at least two vectorial quantities that form a resultant flux of said rotating electric machine during an operation.

55. The method according to claim 53, further comprising the step of:

controlling a phase position as well as an amplitude and a speed of rotation relative to another flux generated by said distribution network of at least one first vectorial quantity of said at least two vectorial quantities.

56. The method according to claim 54, further comprising the step of:

controlling a phase position as well as an amplitude and a speed of rotation relative to a flux generated by said distribution network of at least one first vectorial quantity of said at least two vectorial quantities.

57. The method according to claim 55, wherein said step of controlling further comprises the steps of:

generating said at least one first vectorial quantity of said at least two vectorial quantities via an extra winding mounted on said rotating electric machine and magnetization equipment connected to said rotating electric machine; and

generating at least one second vectorial quantity of said at least two vectorial quantities via an ordinary winding of said rotating electric machine.

58. The method according to claim 57, wherein said step of controlling further comprises:

setting a speed of said rotating electric machine in a generator operating mode;

wherein said rotating electric machine having an asynchronous rotor.

59. The method according to claim 57, wherein said step of controlling further comprises:

setting a speed of said rotating electric machine in a motor operating mode;

wherein said rotating electric machine having an asynchronous rotor.

60. The method according to claim 57, wherein said step of controlling further comprises:

damping a harmonic content of a stator voltage in said ordinary winding of said rotating electric machine.

61. The method according to claim 57, wherein said step of generating said at least one first vectorial quantity comprises:

injecting a reactive magnetization current via said extra winding sufficient to control a voltage of said rotating electric machine on said ordinary winding of said rotating electric machine in at least one of a rotating electric machine connected to a main power terminal and a rotating electric machine not connected to a main power terminal.

62. The method according to claim 58, wherein said rotating electric machine having a permanent magnet rotor connected to said asynchronous rotor and being configured to generate a magnetization current and an other auxiliary power.

63. The method according to claim 58, further comprising:

generating a magnetization current and an other auxiliary power with a permanent magnet rotor connected to said asynchronous rotor

64. The method according to claim 55, further comprising:

switching interruption-free between a generator operating mode and a motor operating mode.

65. The method according to claim 53, wherein

said at least two vectorial quantities being a rotating flux on a stator side of said rotating electric machine F_1 and a flux generated by a rotor current F_2 that together provide a resultant flux F in said rotating electric machine as given by

$$F = F_1 + F_2 \quad ; \text{and}$$

said rotating flux on a stator side of said rotating electric machine F_1 is equal to a sum of a rotating flux generated by both a current in an ordinary winding $F_{1stator}$ with a speed of rotation dependent on a frequency of said distribution network and a number of pole pairs in said rotating electric machine, and a rotating flux generated by the current in an extra winding F_{1magn} controllable with respect to a phase position as well as an amplitude and a frequency relative to a flux vector of the ordinary winding as expressed by

$$F_1 = F_{1magn} + F_{1stator} .$$

66. The method according to claim 53, further comprising:

controlling said at least two vectorial quantities in said rotating electric machine using a relative phase position as well as a relative amplitude value between an active current value and a reactive current value of an ordinary winding and an extra winding.

67. A system configured to adapt a speed of a rotating electric machine included in the system, comprising:

means for generating a flux composed of at least two vectorial quantities for said rotating electric machine during an operation of said rotating electric machine; and

at least two electric windings, wherein said at least two electric windings include;

means for conducting electricity,

means for connecting a semiconductor to said means for conducting electricity,

means for insulating means for connecting, and

means for creating an equipotential surface around said means for insulating,

wherein said rotating electric machine being configured to be directly connected to a distribution network.--

REMARKS

Favorable consideration of this Application as presently amended is respectfully requested.

Claims 33-67 are active in the present Application; Claims 1-32 having been canceled and Claims 33-67 added by way of the present Preliminary Amendment. The new claims have been added to draft the canceled claims in a manner consistent with U.S. practice. It is therefore believed that no issues of new matter have been raised.

Entry of the enclosed substitute specification is respectfully requested. Because several amendments have been made to the specification, consistent with U.S. patent drafting practice, a marked-up copy of the original application is filed herewith. To the extent that any changes made by the substitute specification are deemed to be substantively inconsistent with the originally filed specification, these changes should be construed as typographical errors and the language included in the originally-filed PCT application should be construed as containing the controlling language.

The present document is one of a set of patent applications containing related technology as was discussed in "response to petition under 37 C.F.R. §1.182 seeking special treatment relating to an electronic search tool, and decision on petition under 37 C.F.R. §1.183 seeking waiver of requirements under 37 C.F.R. §1.98," filed in the holding application (U.S. Patent Application No. 09/147,325). Consistent with this decision, a copy of the decision is filed herewith. Also, an Information Disclosure Statement is filed herewith including a PTO Form 1449 with references that are included as part of the specially-created official digest in class 174. It is believed that submission of these materials and the reference to the holding application (Serial No. 09/147,325) is sufficient for the present Examiner to consider the references in the holding application, consistent with the decision.

Accordingly, examination on the merits of Claims 33-67 is believed to be in order, and an early and favorable action is respectfully requested.

Respectfully submitted,

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09/554905

Marked up Specification

526 Rec'd PCT/PTO 22 MAY 2000

SUBSTITUTE SPECIFICATION

~~DOCKET NO:~~ 9847-0048-6X~~x~~PCT

ENKEL 8335

TITLE OF THE INVENTION

A METHOD AND A SYSTEM FOR SPEED CONTROL OF A ROTATING ELECTRICAL MACHINE WITH FLUX COMPOSED OF TWO QUANTITIES

CROSS REFERENCE TO RELATED PATENT DOCUMENTS

The present document is based on published international patent application No. WO 99/29034, the entire contents of which being incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

~~According to a first aspect, t~~The present invention relates to a system and a method for the adaptation, ~~/~~optimization, and/or control of the speed of a rotating electric machine ~~included in the system, which machine is~~ intended to be directly connected to a distribution or transmission network.

~~According to a second aspect of the present invention, it relates to a method for speed control of a rotating electric machine, which machine is intended to be directly connected to a distribution or transmission network.~~

Discussion of the Background:

The rotating electric machine which occurs in the present invention may be, for example, a synchronous machine, an asynchronous machine, a double-fed machine, an asynchronous converter cascade, an external pole machine or a synchronous flux machine.

To connect machines of this kind to distribution or transmission networks, hitherto transformers have been used for step-up transformation of the voltage to network level, that is, to the range of 130-400 kV.

Generators with a rated voltage of up to 36 kV are described by Paul R. Siedler, "36 kV Generators Arise from Insulation Research", Electrical World, 15 October 1932,

pages 524-537. These generators ~~comprise~~ have windings of high-voltage cable, wherein the insulation is divided into different layers with different dielectric constants. The insulating material used ~~comprises~~ is commonly formed of different combinations of ~~the~~ three components, namely, mica, foil-mica, varnish, and paper.

Now, it has ~~proved~~ been shown that by manufacturing windings of a~~the~~ machine~~,~~ ~~mentioned in the introduction, of~~ using an insulated electric high-voltage conductor with a solid insulation ~~of a similar kind~~such as used in cables for power transmission, the voltage of the machine may be increased to ~~such~~ levels such that the machine may be directly connected to any power network without intermediate transformers. A typical operating range for these machines is 30-800 kV.

The insulated conductor or high-voltage cable which is used in the present invention is flexible and of the kind described in more detail in PCT applications SE97/00874 (WO 97/45919) and SE97/00875 (WO 97/45847). A further description of the insulated conductor or cable is to be found in PCT-applications SE97/00901 (WO 97/45918), SE97/00902 (WO 97/45930) and SE97/00903 (WO 97/45931).

In the device according to the invention, the windings are preferably of a kind corresponding to cables with a solid extruded insulation which are currently used for power distribution, for example so-called XLPE cables or cables with EPR insulation. Such a cable has~~comprises~~ an inner conductor composed of one or more strands, an inner semiconductor layer surrounding the conductor, a solid insulating layer surrounding the semiconducting layer, and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the device according to the invention is primarily based on a winding system where the winding is made with wires which are drawn back and forth a plurality of turns, that is, without joints in the coil ends which are required when the winding in the core contains~~consists of~~ stiff conductors. An XLPE cable normally has a flexibility corresponding to a radius of curvature of about 20 cm for a cable with a diameter of 30 mm and a radius of curvature of about 65 cm for a cable with a diameter of 80 cm. The expression "flexible" in this context~~application~~ thus ~~means~~ indicates that the winding is flexible down to a radius of curvature in the order of magnitude of 8-25 times the cable diameter.

The winding should be made such that it may maintain its properties also when being bent and when, during operation, it is subjected to thermal stresses. It is of great im-

portance in this connection that the layers maintain their adhesion to one another. Of decisive importance in this connection are the material properties of the layers, above all their elasticities~~y~~ and their relative coefficients of thermal expansion. For an XLPE cable, for example, the insulating layer is of crosslinked low-density polyethylene and the semiconducting layers of polyethylene with soot and metal particles mixed thereinto. Volume changes as a result of temperature variations are absorbed entirely as changes in radius in the cable, and because of the comparatively slight difference in the coefficients of thermal expansion of the layers in relation to the elasticities~~y~~ of these materials, the radial expansion of the cable will be able to take place without the layers loosening or delamninating from each other.

The material combinations described above are only to be considered as examples. The scope of the invention of course ~~comprises~~ also includes other combinations which fulfil the conditions mentioned and which fulfil the conditions of being semiconducting, that is, with a mass resistivity in the range $1\text{-}10^5$ ~~(~~Ω–cm, and of being insulating, that is, with a mass resistivity greater than 10^5 ~~(~~Ω–cm, respectively.

The insulating layer may, for example, be formed in whole or in part of~~comprise~~ a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene (PMP), crosslinked materials such as crosslinked polyethylene (XLPE) or rubber, such as ethylene-propylene rubber (EPR) or silicone rubber.

The inner and outer semiconducting layers may have the same base materials but mixed with particles of conducting materials, such as soot or metal powder.

The mechanical properties of these materials, primarily their coefficients of thermal expansion, are influenced to a rather slight extent by whether they are~~it is~~ mixed with soot or metal powder or not. The insulating layer and the semiconducting layers will thus have substantially ~~largely~~ the same coefficients of thermal expansion.

For the semiconducting layers, also ethylene vinyl acetate copolymer/nitrile rubber, butyl-grafted polyethylene, ethylene acrylate copolymer, ethylene ethyl acrylate copolymer and ethylene butyl acrylate copolymer may constitute suitable polymers.

Also when different layers of materials are used as a base in the respective layers, it is desirable for their coefficients of thermal expansion to be of the same order of magnitude. This is true of the combination of the materials listed above.

The materials listed above have quite a good elasticity which is sufficient for any minor deviations in the coefficients of thermal expansion of the materials in the layers to be taken up in the radial direction of the elasticity such that cracks or other damage do not arise and such that the layers do not become detached from each other.

The conductivity of the two semiconducting layers is sufficiently great to substantially equalize the potential along the respective layer. At the same time, the conductivity is so low that the outer semiconducting layer has sufficient resistivity to enclose or contain the electric field in the cable.

Each of the two semiconducting layers thus essentially constitutes an equipotential surface and the winding with these layers will substantially enclose the electric field within it.

It is, of course, not excluded that one or several further semiconducting layers may be arranged in the insulating layer.

It is previously known to achieve a more efficient and flexible operation of hydroelectric power stations/pump storage plants with, for example, VARSPEED generators, and that each turbine has an optimum working point, at which speed~~,~~ net head and water flow are adapted to one another to give maximum efficiency. For large machines, the speed may be controlled in several ways, for example by pole switching, stator supply and frequency adaptation ~~by means~~ through the use of frequency converters or ~~by means~~ of a sub- and supersynchronous converter cascade which feeds an asynchronous machine from two directions, that is, both via a stator and a rotor. The rotating three-phase rotor winding and the stationary frequency converter equipment for control of the rotor flux and hence the slip frequency for speed optimization take place via slip rings.

Use of slip rings in speed optimization entails a number of disadvantages such as wear, fouling and hence increased maintenance costs.

SUMMARY OF THE INVENTION

The object of the present invention is to solve the above-mentioned problems. This is achieved with a system for adaptation/optimization of the speed of a rotating electric machine included in the system ~~according to claims 1 and 9,~~ and with a method for speed control of a rotating electric machine as described herein ~~according to claims 18 and 19~~. The machine included in the system according to a first embodiment of the present invention ~~comprises~~ has at least two electric windings, each of which ~~comprises~~ is formed from at least one electric conductor, a first semiconducting layer arranged surrounding the conductor, an insulating layer arranged surrounding the first semiconducting layer, and a second semiconducting layer arranged surrounding the insulating layer. In addition, the system ~~comprises means~~ has mechanisms which generate the resultant stator and air gap flux of the machine during~~in~~ operation, where the~~which~~ flux is composed of at least two vectorial quantities.

One advantage of the system according to the present invention is that no slip rings occur, which, inter alia, entails simplified maintenance and no losses as a result of brush voltage drop. In addition, a rapid demagnetization in case of fault may be obtained.

An advantageous embodiment of the system is obtained in accordance with the invention in that the potential of the first semiconducting layer is essentially equal to the potential of the conductor.

In connection therewith, it is an advantage if the second semiconducting layer is arranged to form essentially an equipotential surface, surrounding the conductor.

An additional advantage in this connection is obtained if the second semiconducting layer is connected to a predetermined potential.

In connection therewith, it is an advantage if the predetermined potential is ground potential.

A further advantage in connection therewith is obtained if at least two adjacent layers of the windings of the machine have essentially equal coefficients of thermal expansion.

In connection therewith, it is an advantage if the conductor ~~comprises~~ has a number of strands, of which at least some are in electric contact with one another.

A further advantage in connection therewith is obtained if each one of the three layers mentioned is secured to adjacent layers along essentially the whole contact surface.

According to a second embodiment of the system according to the invention, the machine included in the system ~~comprises~~ includes at least two electric winding, each of which ~~being~~ is formed from a high-voltage cable ~~comprising~~ having one or more current-carrying conductors, each conductor exhibiting a number of strands, a first semiconducting layer arranged around each conductor, an insulating layer of solid insulating material arranged around the first semiconducting layer, and a second semiconducting layer arranged around the insulating layer. In addition, the system ~~comprises means~~ has a mechanism which generates the resultant stator and air gap flux of the machine in operation, which flux is composed of at least two vectorial quantities.

One advantage of the system according to the second embodiment of the present invention is that no slip rings occur, which, inter alia, entails simplified maintenance and no losses as a result of brush voltage drop. In addition, a rapid demagnetization in case of fault may be obtained.

An additional advantage in connection therewith is obtained if the insulating conductor or the high-voltage cable is flexible.

In connection therewith, it is an advantage if the layers are arranged to adhere to one another even if the insulating conductor or the high-voltage cable is bent.

An additional advantage in connection therewith is that the flux-generating member ~~comprises~~ has an extra winding arranged on the machine and magnetization equipment connected to the machine, whereby one flux vector is generated via the extra winding and the magnetization equipment and one flux vector is generated via the ordinary winding of the machine.

In connection therewith, it is an advantage if the magnetization equipment ~~consists~~ contains~~of~~ a first frequency converter.

An additional advantage in this connection is obtained if the system furthermore ~~comprises~~ has an auxiliary feeder connected to the first frequency converter and the machine.

In connection therewith, it is an advantage if the machine ~~comprises~~is formed from an asynchronous rotor, and if the auxiliary feeder ~~comprises~~ has a stator winding and a permanent-magnet rotor connected to the asynchronous rotor.

An additional advantage in connection therewith is obtained if the system furthermore ~~comprises~~ has a transformer connected to the first frequency converter and the

auxiliary feeder, where the~~which~~ transformer is connected to a distribution busbar via a first circuit breaker, and a second frequency converter connected to the transformer, where the~~which~~ second frequency converter is connected to the distribution busbar via a second circuit breaker.

In connection therewith, it is an advantage if the windings are flexible and if the mentioned layers make contact with one another.

An additional advantage in this connection is if the mentioned layers are of materials with such elasticities~~y~~ and such a relation between the coefficients of thermal expansion of the materials that the volume changes of the layers, caused by temperature variations during operation, are capable of being absorbed by the elasticity of the materials such that the layers ~~retain their~~remain in contact with one another at the temperature variations which occur during operation.

In connection therewith, it is an advantage if the materials in the layers mentioned have a high elasticity.

An additional advantage in connection therewith is obtained if each semiconducting layer constitutes essentially an equipotential surface.

The method according to a first embodiment of the present invention for speed control of a rotating electric machine is applicable to a machine which is intended to be directly connected to a distribution or transmission network. The machine ~~comprises~~ is formed from at least two electric windings, each of which ~~comprises~~ has at least one electric conductor, a first semiconducting layer arranged surrounding the conductor, an insulating layer arranged surrounding the first semiconducting layer, and a second semiconducting layer arranged surrounding the insulating layer. The method includes ~~comprises~~ the step of generating at least two vectorial quantities which constitute the resultant stator and air gap flux of the machine during operation.

The method according to a second embodiment of the present invention for speed control of a rotating electric machine is applicable to a machine which is intended to be directly connected to a distribution or transmission network. The machine has~~comprises~~ at least two electric windings, which are each formed from a high-voltage cable having~~comprising~~ one or more current-carrying conductors, whereby each conductor exhibits a number of strands, a first semiconducting layer arranged around each conductor, an insulating layer of solid insulating material arranged around the first semiconducting layer, and a sec-

ond semiconducting layer arranged around the insulating layer. The method includes~~comprises~~ the step of generating at least two vectorial quantities which constitute the resultant stator and air gap flux of the machine during operation.

An advantage of the method according to the two embodiments of the present invention is that no slip rings occur, which, inter alia, entails simplified maintenance and no losses as a result of brush voltage drop. In addition, a rapid demagnetization in case of fault may be obtained.

In connection therewith, an advantage is obtained if the method includes~~comprises~~ the following additional step:

- controlling at least one of the vectorial fluxes with respect to phase position as well as amplitude and speed of rotation relative to the flux generated and rotated by the connecting network.

A further advantage in connection therewith is obtained if the method ~~comprises~~ includes the following steps:

- generating a flux vector via an extra winding, mounted on the stator of the machine, and magnetization equipment connected to the machine, and
- generating a flux vector via the ordinary winding of the machine.

According to a first aspect of the invention, the rotating electric machine ~~comprises~~ additionally includes~~, in addition,~~ an asynchronous rotor, whereby the flux control is used for speed-control of the machine in generator operating mode.

According to a second aspect of the invention, the rotating electric machine ~~comprises, in addition,~~ additionally includes an asynchronous rotor, whereby the flux control is used for speed-control of the machine in motor operating mode.

According to a third aspect of the present invention, the flux control is used to suppress the harmonic content of the stator voltage in the ordinary stator winding of the machine.

According to a fourth aspect of the present invention, the reactive magnetization current of the machine is injected via the extra winding, which makes possible control of the voltage of the machine on the ordinary winding of the machine both for a non-mains-connected and a mains-connected machine.

In connection therewith, it is an advantage if the rotating electric machine furthermore ~~comprises~~ includes a permanent-magnet rotor, connected to the asynchronous rotor, for generating magnetization current and other auxiliary power.

According to a further aspect of the present invention, the flux control is used for interruption-free change from generator operating mode to motor operating mode and vice versa.

In connection therewith, it is an advantage if the resultant flux in the machine is:

$$\Phi = \Phi_1 + \Phi_2$$ ~~(Komplettera med vektorstreck !)~~

where Φ_1 is the rotating flux on the stator side of the machine and Φ_2 is the flux generated by the rotor current, whereby

$$\Phi_1 = \Phi_{1magn} + \Phi_{1stator}$$ ~~(Komplettera med vektorstreck !)~~

where $\Phi_{1stator}$ is the rotating flux generated by the current in the ordinary winding, whereby the speed of rotation on $\Phi_{1stator}$ is dependent on the frequency of the network and the number of pole pairs in the machine, and Φ_{1magn} is the rotating flux generated by the current in the extra winding, which flux is controllable with respect to phase position as well as amplitude and frequency relative to the flux vector of the ordinary winding.

An additional advantage in connection therewith is obtained if the vectorially created flux in the machine is controlled with the aid of the relative phase position as well as the relative amplitude value between the active and reactive current values of the ordinary winding (54) and the extra winding (56).

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be explained in greater detail by the following description of preferred embodiments of the invention with reference to the accompanying drawings.

Figure 1 is a cross-section view of a high-voltage cable;

Figure 2 is a diagram which shows a system according to the present invention for adaptation/optimization of the speed of a rotating electric machine included in the system;

Figures 3a and 3b are schematic figures which more clearly show the solution on principle for the system shown in Figure 2;

Figures 4a and 4b are schematic figures which for the purpose of clarification show, respectively, the rotating fluxes and the electromotive force (EMF) induced in the rotor part in the system shown in Figure 2;

Figures 5a, 5b and 5c are three diagrams which illustrate the principle of control/change of the speed of rotation for the resultant flux in the machine in the system shown in Figure 2; and

Figure 6 is a flow diagram of the method according to the present invention for speed control of a rotating electric machine.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows a cross-section view of a high-voltage cable 10 which is traditionally used for transmission of electric power. The high-voltage cable 10 shown may, for example, be a standard XLPE cable 145 kV but without a sheath of screen. The high-voltage cable 10 ~~comprises~~ has an electric conductor, which may ~~comprise~~ have one or more strands 12 of circular cross section of, for example, copper (Cu). These strands 12 are arranged in the centre of the high-voltage cable 10. Around the strands 12 there is a first semiconducting layer 14. Around the first semiconducting layer 14 there is an insulating layer 16, for example XLPE insulation. Around the insulating layer 16 there is a second semiconducting layer 18. In the high-voltage cable 10 shown, the three layers 14, 16, 18 are designed so as to adhere to one another also when the cable 10 is bent. The shown cable 10 is flexible and this property is retained in the cable 10 during its service life.

Figure 2 shows a diagram of a system according to the present invention for adaptation/optimization of the speed of a rotating electric machine included in the system. The system 20 ~~comprises~~ includes a rotating electric machine 22, which is directly connected to a distribution or transmission network 24. The rotating electric machine 24 ~~comprises~~ has at least two windings, wherein each winding in a first embodiment of the present invention contains~~comprises~~ at least one conductor, a first semiconducting layer arranged surrounding the conductor, an insulating layer arranged surrounding the first semiconducting layer, and a second semiconducting layer arranged surrounding the insulating layer. According to a second embodiment of the system 20 according to the present invention, the windings are each formed from the high-voltage cable 10 shown in Figure 1. The system 20 ~~comprises, in addition,~~ additionally has a member 26 which generates the resul-

tant stator and air gap flux of the machine in operation, which flux is composed of at least two vectorial quantities. In addition, the system 20 ~~comprises~~ contains magnetization equipment 28, connected to the rotating electric machine 22, which in the shown example is in the form of a first frequency converter 28. Connected to the rotating electric machine 22 is an auxiliary feeder 30. In addition, the system 20 ~~comprises~~ has a transformer 32 for voltage adaptation, connected to the first frequency converter 28 and the auxiliary feeder 30. The transformer 32, in its turn, is connected to a distribution busbar 36 via a first circuit breaker 34. In addition, the system 20 ~~comprises~~ has a second frequency converter 38 for auxiliary power generation, which second frequency converter 38 is connected, on the one hand, to the transformer 32 and, on the other hand, to the distribution busbar 36 via a second circuit breaker 40.

Figures 3a and 3b schematically show the solution on principle for the system 20 shown in Figure 2. Figure 3a shows the rotor 50 and the stator 52, respectively, of the rotating electric machine 22. The stator 52 is provided in traditional manner with a three-phase winding 54, also called ordinary winding 54 or main winding 54. In addition, the stator 52 is provided with an extra winding 56. When the rotating electric machine 22 is in operation, a rotating flux Φ_1, among other things, is generated on the stator side, which flux Φ_1 rotates in the direction of the dotted arrow. Figure 3b shows a part of the system 20 shown in Figure 2 which is of importance to the present invention. Again, the main winding 54 (three-phase) and the extra winding 56 (three-phase) of the stator are shown, the extra winding 56 being connected to the first frequency converter 28. In addition, the stator winding 58 (three-phase) of the auxiliary feeder 30 (cf. Fig. 2) is shown, which is also connected to the first frequency converter 28. The rotating electric machine 22 (cf. Fig. 2) ~~comprises, in addition,~~ additionally includes an asynchronous rotor 60 for the main winding 54 and the extra winding 56 of the stator. In addition, Figure 3b shows a permanent-magnet rotor 62 included in the auxiliary feeder 30 (cf. Fig. 2). The permanent-magnet rotor 62 is connected to the asynchronous rotor 60 so that these rotate together. The system 20 may be used for adaptation/optimization of the speed of a rotating electric machine 22 included in the system 20. This is achieved by composing the rotating flux Φ_1 on the stator side 52 (cf. Fig. 3) from at least two flux vectors. One flux vector is generated in traditional manner via the main winding 54 of the stator 52 and one flux vector is generated via the extra winding 56 of the stator 52 and the first frequency converter 28. By controlling the

flux vector, generated via the extra winding 56 and the first frequency converter 28, with respect to phase position as well as amplitude and frequency relative to the flux vector generated via the main winding 54, the angular velocity of the total flux vector may rotate both supersynchronously and subsynchronously related to the flux vector generated via the main winding.

Figures 4a and 4b schematically show the rotating fluxes and the EMF induced in the rotor part, respectively, in the system shown in Figure 2. Figure 4a again shows parts of the rotating electric machine 22 (cf. Fig. 2) in the form of the rotor 50 and the stator 52. As is also clear from Figure 3a, the stator 52 is provided with a main winding 54 and an extra winding 56. The rotor 50 rotates in the direction of the arrow A. The rotating total flux Φ_1 of the stator 52 rotates in the direction of the arrow B with the speed $n_{\Phi 1}$. The total generated flux for the machine 22 in operation is

$$\Phi = \Phi_1 + \Phi_2$$

~~(Komplettera med vektorstreck !)~~

where Φ_1 is the rotating flux on the stator side, and Φ_2 is the flux generated by the rotor current. The rotating flux Φ_1 on the stator side may be expressed as follows

$$\Phi_1 = \Phi_{1magn} + \Phi_{1stator}$$

~~(Komplettera med vektorstreck !)~~

where $\Phi_{1stator}$ is the rotating flux generated by the current in the main winding 54, and Φ_{1magn} is rotating and controllable flux. Φ_{1magn} is generated via the extra winding 56 of the stator 52 and the first frequency converter 28. Figure 4b schematically shows the rotor 50. The rotating air gap flux induces a winding EMF, e_{rotor}, in the rotor winding. The rotor current, I_{rotor}, driven by the EMF e_{rotor} gives rise to a torque Mv. The winding EMF e_{rotor} may be expressed as

$$e_{rotor} = k1 \text{ x } \Phi_1 \text{ x } (n_{rotor} - n_{\Phi 1})$$

The torque may be expressed as

$$Mv = k2 \text{ x } \Phi_1 \text{ x } I_{rotor}$$

where k1, k2 are constants, n_{rotor} is the speed of the rotor 50, which may be changed and adapted for optimization of, for example, the efficiency of the turbine, and $n_{\Phi 1}$ is the speed of the rotating flux Φ_1 on the stator side, whereby the speed $n_{\Phi 1}$ may be changed and adapted for slip optimization.

Figures 5a, 5b and 5c show three different diagrams which illustrate the principle of control/change of the speed of rotation for the resultant flux Φ_1 on the stator side in the

machine 22 in the system 20 shown in Figure 2. Figure 5a shows how $\Phi_{1stator}$ varies with the time t. The speed of rotation of $\Phi_{1stator}$ depends on the frequency of the network (cf. Fig. 2) and the number of pole pairs in the rotating electric machine 22. Figure 5b shows how Φ_{1magn} varies with the time t. The amplitude, frequency and phase position of Φ_{1magn} are determined with respect to the desired speed of rotation of Φ_1. Figure 5c shows how the resultant rotating flux Φ_1 in the stator 52 varies with the time t.

Figure 6 shows a flow diagram of the method according to the present invention for speed control of a rotating electric machine. The method according to the present invention ~~comprises~~ includes a number of steps which will be described below. The flow diagram starts at block 70. The next step, at block 72, ~~comprises~~ includes starting and connecting the rotating electric machine 22 to the network (cf. Fig. 2). Thereafter, at block 74, at least two vectorial quantities are generated, which constitute the resultant stator and air gap flux of the machine in operation. Provided that there are two vectorial quantities, one flux vector $\Phi_{1stator}$ is generated via the main winding 54 of the stator 52, and one flux vector Φ_{1magn} is generated via the extra winding 56 of the stator 52 and the first frequency converter 28. Thereafter, at block 76, it is inquired whether the speed of the machine is suitable. If the question is answered in the affirmative, block 76 is reiterated. On the other hand, if the answer is negative, the method continues to block 78. In block 78, the step of controlling at least one of the vectorial fluxes with respect to phase position as well as amplitude and frequency (speed of rotation) relative to the flux generated and rotated by the connecting network is carried out. This control implies that the machine has the desired/appropriate speed. Thereafter, at block 80, it is inquired whether the machine is to be in operation. If the question is answered in the affirmative, block 76 is reiterated. On the other hand, if the answer is negative, the method continues to block 82. At block 82, the operation of the machine is stopped. At block 84, the method is terminated.

The invention is not limited to the embodiments shown but several modifications are feasible within the scope of the inventive concept. Thus adaptation of the slip frequency may take place both during motor and generator operation and by suitable dimensioning of the frequency converter equipment, all operating modes may, in principle, be met.

In addition, the principle may be applied to rapid, interruption-free change from motor operation to generator operation in, for example, industrial applications.

Further, the principle may be applied to reduction/elimination of the harmonic content in the stator voltage of a machine. The principle may be applied to both synchronous and asynchronous machines.

In addition, the frequency converter equipment and the extra winding of the stator may be used both when starting the machine upon start-up and when braking the machine upon shutdown.

Further, the angular velocity of the flux vector generated via the extra winding is controllable via the stationary frequency converter equipment and hence an optimum operating position for adaptation to a changed turbine speed caused by changed net head may always occur.

In addition, the vectorially created flux in the machine may be controlled with the aid of the relative phase position as well as the relative amplitude position between the active and reactive current values of the ordinary winding and the extra winding.

The invention is not limited to the embodiments shown, but several variants are feasible within the scope of the appended claims.

CLAIMS

1. A system (20) for adaptation/optimization of the speed of a rotating electric machine (22) included in the system (20), which machine (22) is intended to be directly connected to a distribution or transmission network (24) and comprising at least two electric windings, characterized in that the winding each comprises at least one electric conductor, a first semiconducting layer (14) arranged surrounding the conductor, an insulating layer (16) arranged surrounding the first semiconducting layer (14), and a second semiconducting layer (18) arranged surrounding the insulating layer (16), and that the system (20) comprises ~~means~~ mechanisms(26) which generate the resultant stator and air gap flux of the machine (22) during operation, which flux is composed of at least two vectorial quantities.

2. A system (20) according to claim 1, characterized in that the potential of the first semiconducting layer (14) is essentially equal to the potential of the conductor.

3. A system (20) according to claim 1 or 2, characterized in that the second semiconducting layer (18) is adapted to form essentially one equipotential surface, surrounding the conductor.

4. A system (20) according to claim 3, characterized in that the second semiconducting layer (18) is connected to a predetermined potential.

5. A system (20) according to claim 4, characterized in that said predetermined potential is ground potential.

6. A system (20) according to any of the preceding claims, characterized in that at least two adjacent layers of the windings of the machine have essentially identical coefficients of thermal expansion.

7. A system (20) according to any of the preceding claims, characterized in that the conductor comprises a number of strands (12), at least some of which are in electric contact with one another.

8. A system (20) according to any of the preceding claims, characterized in that each of said three layers is secured to adjacent layers along essentially the whole contact surface.

9. A system (20) for adaptation/optimization of the speed of a rotating electric machine (22) included in the system (20), which machine is intended to be directly connected to a distribution or transmission network (24) and comprising at least two electric windings, characterized in that the windings are each formed from a high-voltage cable (10) comprising one or more current-carrying conductors, whereby each conductor exhibits a number of strands (12), a first semiconducting layer (14) arranged around each conductor, an insulating layer (16) of solid insulating material arranged around said first semiconducting layer (14), and a second semiconducting layer (18) arranged around the insulating layer (16), and that the system (20) comprises means (26) which generate the resultant stator and air gap flux of the machine (22) in operation, which flux is composed of at least two vectorial quantities.

10. A system (20) according to any of the preceding claims, characterized in that the insulating conductor or high-voltage cable (10) is flexible.

11. A system (20) according to claim 10, characterized in that the layers are arranged to adhere to one another also when the insulated conductor or high-voltage cable (10) is bent.

12. A system (20) according to any of the preceding claims, characterized in that the flux-generating member (26) comprises an extra winding (56), arranged on the stator (52) of the machine (22), and magnetization equipment (28) connected to the machine (22), whereby one flux vector is generated via the extra winding (56) and the magnetization equipment (28) and one flux vector is generated via the ordinary winding (54) of the machine (22).

13. A system (20) according to claim 12, characterized in that the magnetization equipment (28) is in the form of a first frequency converter (28).

14. A system (20) according to claim 13, characterized in that the system (20), in addition, comprises an auxiliary feeder (30) connected to the first frequency converter (28) and the machine (22).

15. A system (20) according to claim 14, characterized in that the machine (22) comprises an asynchronous rotor (60) and that the auxiliary feeder (30) comprises a stator winding (58) and a permanent-magnet rotor (62) connected to the asynchronous rotor (60).

16. A system (20) according to any of claim 14 or 15, characterized in that the system (20), in addition, comprises a transformer (32) connected to the first frequency converter (28) and the auxiliary feeder (30), said transformer being connected to a distribution busbar (36) via a first circuit breaker (34), and a second frequency converter (38) which is connected to the transformer (32) and which is connected to the distribution busbar (36) via a second circuit breaker (40).

17. A system (20) according to claim 1, characterized in that the windings are flexible and in that said layers make contact with one another.

18. A system (20) according to claim 17, characterized in that said layers are of a material with such elasticity and such a relation between the coefficients of thermal expansion of the materials that the volume changes of the layers, caused by temperature variations during operation, are capable of being absorbed by the elasticity of the materials such that the layers retain their contact with one another at the temperature variations which occur during operation.

19. A system (20) according to claim 18, characterized in that the materials in said layers have a high elasticity.

20. A system (20) according to claim 18, characterized in that each semiconducting layer constitutes essentially an equipotential surface.

21. A method for speed control of a rotating electric machine (22), which machine (22) is intended to be directly connected to a distribution or transmission network (24) and comprising at least two electric windings, each winding comprising at least one electric conductor, a first semiconducting layer (14) arranged surrounding the conductor, an insulating layer (16) arranged surrounding the first semiconducting layer (14), and a second semiconducting layer (18) arranged surrounding the insulating layer (16), which method comprises the following step:

- generating at least two vectorial quantities which constitute the resultant stator and air gap flux of the machine (22) during operation.

22. A method for speed control of a rotating electric machine (22), which machine (22) is intended to be directly connected to a distribution or transmission network (24) and comprising at least two electric windings, each winding being formed of a high-voltage cable (10) comprising one or more current-carrying conductors, whereby each conductor exhibits a number of strands, a first semiconducting layer (14) arranged around each conductor, an insulating layer (16) of solid insulating material arranged around said first semiconducting layer (14), and a second semiconducting layer (18) arranged around the insulating layer (16), which method comprises the following step:

- generating at least two vectorial quantities which constitute the resultant stator and air gap flux of the machine (22) during operation.

23. A method according to any of claim 21 or 22, which method is characterized by the following additional step:

- controlling at least one of the vectorial fluxes with respect to phase position as well as amplitude and speed of rotation relative to the flux generated and rotated by the connecting network (24).

24. A method according to claim 23, characterized by the following steps:

- generating a flux vector via an extra winding (56), mounted on the machine (22), and magnetization equipment (28) connected to the machine (22), and
- generating a flux vector via the ordinary winding (54) of the machine (22).

25. A method according to any of claim 23 or 24, characterized in that the rotating electric machine (22), in addition, comprises an asynchronous rotor (60), whereby the flux control is used for speed control of the machine (22) in generator operating mode.

26. A method according to any of claim 23 or 24, characterized in that the rotating electric machine (22), in addition, comprises an asynchronous rotor (60), whereby the flux control is used for speed control of the machine (22) in motor operating mode.

27. A method according to any of claim 23 or 24, characterized in that the flux control is used for damping the harmonic content of the stator voltage in the ordinary winding (54) of the machine (22).

28. A method according to claim 24, characterized in that the reactive magnetization current of the machine (22) is injected via the extra winding (56), whereby it is possible to control the voltage of the machine (22) on the ordinary winding (54) of the machine (22) for both a non-mains-connected and a mains-connected machine (22).

29. A method according to claim 25, characterized in that the rotating electric machine (22), in addition, comprises a permanent-magnet rotor (62), connected to the asynchronous rotor (60), for generating magnetization current and other auxiliary power.

30. A method according to any of claim 23 or 24, characterized in that the flux control is used for interruption-free change from generator operating mode to motor operating mode and vice versa.

31. A method according to any of claims 24-30, characterized in that the resultant flux in the machine (22) is

$$\Phi = \Phi_1 + \Phi_2 \qquad \text{(Komplettera med vektorstreck !)}$$

where Φ_1 is the rotating flux on the stator side of the machine and Φ_2 is the flux generated by the rotor current, whereby

$$\Phi_1 = \Phi_{1magn} + \Phi_{1stator} \qquad \text{(Komplettera med vektorstreck !)}$$

where $\Phi_{1stator}$ is the rotating flux generated by the current in the ordinary winding

(54), whereby the speed of rotation on $\Phi_{1stator}$ is dependent on the frequency of the network and the number of pole pairs in the machine (22), and Φ_{1magn} is the rotating flux generated by the current in the extra winding (56), which flux is controllable with respect to phase position as well as amplitude and frequency relative to the flux vector of the ordinary winding (54).

32. A method according to claim 24, characterized in that the vectorially created flux in the machine (22) is controlled with the aid of the relative phase position as well as the relative amplitude value between the active and reactive current values of the ordinary winding (54) and the extra winding (56).

ABSTRACT OF THE DISCLOSURE

The invention relates to a system ~~(20)~~ for adaptation/optimization of the speed of a rotating electric machine ~~(22)~~ included in the system ~~(20)~~, ~~which~~ wherein the machine is intended to be directly connected to a distribution or transmission network ~~(24)~~. The machine ~~(22) comprises~~ has at least two electric windings, each of which ~~comprises~~ is formed from at least one electric conductor, a first semiconducting layer ~~(14)~~ arranged surrounding the conductor, an insulating layer ~~(16)~~ arranged surrounding the first semiconducting layer ~~(14)~~, and a second semiconducting layer ~~(18)~~ arranged surrounding the insulating layer ~~(16)~~. In addition, the system ~~(20) comprises means (26) which~~ is configured to generate a~~the~~ resultant stator and air gap flux of the machine ~~(22)~~ during operation, ~~which~~ wherein the flux is composed of at least two vectorial quantities.

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SUBSTITUTE SPECIFICATION

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TITLE OF THE INVENTION

A METHOD AND A SYSTEM FOR SPEED CONTROL OF A ROTATING ELECTRICAL MACHINE WITH FLUX COMPOSED OF TWO QUANTITIES

CROSS REFERENCE TO RELATED PATENT DOCUMENTS

The present document is based on published international patent application No. WO 99/29034, the entire contents of which being incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a system and a method for the adaptation, optimization, and/or control of the speed of a rotating electric machine intended to be directly connected to a distribution or transmission network.

Discussion of the Background:

The rotating electric machine which occurs in the present invention may be, for example, a synchronous machine, an asynchronous machine, a double-fed machine, an asynchronous converter cascade, an external pole machine or a synchronous flux machine.

To connect machines of this kind to distribution or transmission networks, hitherto transformers have been used for step-up transformation of the voltage to network level, that is, to the range of 130-400 kV.

Generators with a rated voltage of up to 36 kV are described by Paul R. Siedler, "36 kV Generators Arise from Insulation Research", Electrical World, 15 October 1932, pages 524-537. These generators have windings of high-voltage cable, wherein the insulation is divided into different layers with different dielectric constants. The insulating mate-

rial used is commonly formed of different combinations of three components, namely, mica, foil-mica, varnish, and paper.

Now, it has been shown that by manufacturing windings of a machine using an insulated electric high-voltage conductor with a solid insulation such as used in cables for power transmission, the voltage of the machine may be increased to levels such that the machine may be directly connected to any power network without intermediate transformers. A typical operating range for these machines is 30-800 kV.

The insulated conductor or high-voltage cable which is used in the present invention is flexible and of the kind described in more detail in PCT applications SE97/00874 (WO 97/45919) and SE97/00875 (WO 97/45847). A further description of the insulated conductor or cable is to be found in PCT-applications SE97/00901 (WO 97/45918), SE97/00902 (WO 97/45930) and SE97/00903 (WO 97/45931).

In the device according to the invention, the windings are preferably of a kind corresponding to cables with a solid extruded insulation which are currently used for power distribution, for example so-called XLPE cables or cables with EPR insulation. Such a cable has an inner conductor composed of one or more strands, an inner semiconductor layer surrounding the conductor, a solid insulating layer surrounding the semiconducting layer, and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the device according to the invention is primarily based on a winding system where the winding is made with wires which are drawn back and forth a plurality of turns, that is, without joints in the coil ends which are required when the winding in the core contains stiff conductors. An XLPE cable normally has a flexibility corresponding to a radius of curvature of about 20 cm for a cable with a diameter of 30 mm and a radius of curvature of about 65 cm for a cable with a diameter of 80 cm. The expression "flexible" in this context thus indicates that the winding is flexible down to a radius of curvature in the order of magnitude of 8-25 times the cable diameter.

The winding should be made such that it may maintain its properties also when being bent and when, during operation, it is subjected to thermal stresses. It is of great importance in this connection that the layers maintain their adhesion to one another. Of decisive importance in this connection are the material properties of the layers, above all their elasticities and their relative coefficients of thermal expansion. For an XLPE cable, for ex-

ample, the insulating layer is of crosslinked low-density polyethylene and the semiconducting layers of polyethylene with soot and metal particles mixed thereinto. Volume changes as a result of temperature variations are absorbed entirely as changes in radius in the cable, and because of the comparatively slight difference in the coefficients of thermal expansion of the layers in relation to the elasticities of these materials, the radial expansion of the cable will be able to take place without the layers loosening or delamninating from each other.

The material combinations described above are only to be considered as examples. The scope of the invention of course also includes other combinations which fulfil the conditions mentioned and which fulfil the conditions of being semiconducting, that is, with a mass resistivity in the range $1\text{-}10^5$ Ω–cm, and of being insulating, that is, with a mass resistivity greater than 10^5 Ω–cm, respectively.

The insulating layer may, for example, be formed in whole or in part of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene (PMP), crosslinked materials such as crosslinked polyethylene (XLPE) or rubber, such as ethylene-propylene rubber (EPR) or silicone rubber.

The inner and outer semiconducting layers may have the same base materials but mixed with particles of conducting materials, such as soot or metal powder.

The mechanical properties of these materials, primarily their coefficients of thermal expansion, are influenced to a rather slight extent by whether they are mixed with soot or metal powder or not. The insulating layer and the semiconducting layers will thus have substantially the same coefficients of thermal expansion.

For the semiconducting layers, also ethylene vinyl acetate copolymer/nitrile rubber, butyl-grafted polyethylene, ethylene acrylate copolymer, ethylene ethyl acrylate copolymer and ethylene butyl acrylate copolymer may constitute suitable polymers.

Also when different layers of materials are used as a base in the respective layers, it is desirable for their coefficients of thermal expansion to be of the same order of magnitude. This is true of the combination of the materials listed above.

The materials listed above have quite a good elasticity which is sufficient for any minor deviations in the coefficients of thermal expansion of the materials in the layers to

be taken up in the radial direction of the elasticity such that cracks or other damage do not arise and such that the layers do not become detached from each other.

The conductivity of the two semiconducting layers is sufficiently great to substantially equalize the potential along the respective layer. At the same time, the conductivity is so low that the outer semiconducting layer has sufficient resistivity to enclose or contain the electric field in the cable.

Each of the two semiconducting layers thus essentially constitutes an equipotential surface and the winding with these layers will substantially enclose the electric field within it.

It is, of course, not excluded that one or several further semiconducting layers may be arranged in the insulating layer.

It is previously known to achieve a more efficient and flexible operation of hydroelectric power stations/pump storage plants with, for example, VARSPEED generators, and that each turbine has an optimum working point, at which speed net head and water flow are adapted to one another to give maximum efficiency. For large machines, the speed may be controlled in several ways, for example by pole switching, stator supply and frequency adaptation through the use of frequency converters or of a sub- and supersynchronous converter cascade which feeds an asynchronous machine from two directions, that is, both via a stator and a rotor. The rotating three-phase rotor winding and the stationary frequency converter equipment for control of the rotor flux and hence the slip frequency for speed optimization take place via slip rings.

Use of slip rings in speed optimization entails a number of disadvantages such as wear, fouling and hence increased maintenance costs.

SUMMARY OF THE INVENTION

The object of the present invention is to solve the above-mentioned problems. This is achieved with a system for adaptation/optimization of the speed of a rotating electric machine included in the system and with a method for speed control of a rotating electric machine as described herein. The machine included in the system according to a first embodiment of the present invention has at least two electric windings, each of which is formed from at least one electric conductor, a first semiconducting layer arranged surrounding the conductor, an insulating layer arranged surrounding the first semiconducting

layer, and a second semiconducting layer arranged surrounding the insulating layer. In addition, the system has mechanisms which generate the resultant stator and air gap flux of the machine during operation, where the flux is composed of at least two vectorial quantities.

One advantage of the system according to the present invention is that no slip rings occur, which, inter alia, entails simplified maintenance and no losses as a result of brush voltage drop. In addition, a rapid demagnetization in case of fault may be obtained.

An advantageous embodiment of the system is obtained in accordance with the invention in that the potential of the first semiconducting layer is essentially equal to the potential of the conductor.

In connection therewith, it is an advantage if the second semiconducting layer is arranged to form essentially an equipotential surface, surrounding the conductor.

An additional advantage in this connection is obtained if the second semiconducting layer is connected to a predetermined potential.

In connection therewith, it is an advantage if the predetermined potential is ground potential.

A further advantage in connection therewith is obtained if at least two adjacent layers of the windings of the machine have essentially equal coefficients of thermal expansion.

In connection therewith, it is an advantage if the conductor has a number of strands, of which at least some are in electric contact with one another.

A further advantage in connection therewith is obtained if each one of the three layers mentioned is secured to adjacent layers along essentially the whole contact surface.

According to a second embodiment of the system according to the invention, the machine included in the system includes at least two electric winding, each of which is formed from a high-voltage cable having one or more current-carrying conductors, each conductor exhibiting a number of strands, a first semiconducting layer arranged around each conductor, an insulating layer of solid insulating material arranged around the first semiconducting layer, and a second semiconducting layer arranged around the insulating layer. In addition, the system has a mechanism which generates the resultant stator and air gap flux of the machine in operation, which flux is composed of at least two vectorial quantities.

One advantage of the system according to the second embodiment of the present invention is that no slip rings occur, which, inter alia, entails simplified maintenance and no losses as a result of brush voltage drop. In addition, a rapid demagnetization in case of fault may be obtained.

An additional advantage in connection therewith is obtained if the insulating conductor or the high-voltage cable is flexible.

In connection therewith, it is an advantage if the layers are arranged to adhere to one another even if the insulating conductor or the high-voltage cable is bent.

An additional advantage in connection therewith is that the flux-generating member has an extra winding arranged on the machine and magnetization equipment connected to the machine, whereby one flux vector is generated via the extra winding and the magnetization equipment and one flux vector is generated via the ordinary winding of the machine.

In connection therewith, it is an advantage if the magnetization equipment contains a first frequency converter.

An additional advantage in this connection is obtained if the system furthermore has an auxiliary feeder connected to the first frequency converter and the machine.

In connection therewith, it is an advantage if the machine is formed from an asynchronous rotor, and if the auxiliary feeder has a stator winding and a permanent-magnet rotor connected to the asynchronous rotor.

An additional advantage in connection therewith is obtained if the system furthermore has a transformer connected to the first frequency converter and the auxiliary feeder, where the transformer is connected to a distribution busbar via a first circuit breaker, and a second frequency converter connected to the transformer, where the second frequency converter is connected to the distribution busbar via a second circuit breaker.

In connection therewith, it is an advantage if the windings are flexible and if the mentioned layers make contact with one another.

An additional advantage in this connection is if the mentioned layers are of materials with such elasticities and such a relation between the coefficients of thermal expansion of the materials that the volume changes of the layers, caused by temperature variations during operation, are capable of being absorbed by the elasticity of the materials such

that the layers remain in contact with one another at the temperature variations which occur during operation.

In connection therewith, it is an advantage if the materials in the layers mentioned have a high elasticity.

An additional advantage in connection therewith is obtained if each semiconducting layer constitutes essentially an equipotential surface.

The method according to a first embodiment of the present invention for speed control of a rotating electric machine is applicable to a machine which is intended to be directly connected to a distribution or transmission network. The machine is formed from at least two electric windings, each of which has at least one electric conductor, a first semiconducting layer arranged surrounding the conductor, an insulating layer arranged surrounding the first semiconducting layer, and a second semiconducting layer arranged surrounding the insulating layer. The method includes the step of generating at least two vectorial quantities which constitute the resultant stator and air gap flux of the machine during operation.

The method according to a second embodiment of the present invention for speed control of a rotating electric machine is applicable to a machine which is intended to be directly connected to a distribution or transmission network. The machine has at least two electric windings, which are each formed from a high-voltage cable having one or more current-carrying conductors, whereby each conductor exhibits a number of strands, a first semiconducting layer arranged around each conductor, an insulating layer of solid insulating material arranged around the first semiconducting layer, and a second semiconducting layer arranged around the insulating layer. The method includes the step of generating at least two vectorial quantities which constitute the resultant stator and air gap flux of the machine during operation.

An advantage of the method according to the two embodiments of the present invention is that no slip rings occur, which, inter alia, entails simplified maintenance and no losses as a result of brush voltage drop. In addition, a rapid demagnetization in case of fault may be obtained.

In connection therewith, an advantage is obtained if the method includes the following additional step:

- controlling at least one of the vectorial fluxes with respect to phase position as well as amplitude and speed of rotation relative to the flux generated and rotated by the connecting network.

A further advantage in connection therewith is obtained if the method includes the following steps:

- generating a flux vector via an extra winding, mounted on the stator of the machine, and magnetization equipment connected to the machine, and
- generating a flux vector via the ordinary winding of the machine.

According to a first aspect of the invention, the rotating electric machine additionally includes an asynchronous rotor, whereby the flux control is used for speed-control of the machine in generator operating mode.

According to a second aspect of the invention, the rotating electric machine additionally includes an asynchronous rotor, whereby the flux control is used for speed-control of the machine in motor operating mode.

According to a third aspect of the present invention, the flux control is used to suppress the harmonic content of the stator voltage in the ordinary stator winding of the machine.

According to a fourth aspect of the present invention, the reactive magnetization current of the machine is injected via the extra winding, which makes possible control of the voltage of the machine on the ordinary winding of the machine both for a non-mains-connected and a mains-connected machine.

In connection therewith, it is an advantage if the rotating electric machine furthermore includes a permanent-magnet rotor, connected to the asynchronous rotor, for generating magnetization current and other auxiliary power.

According to a further aspect of the present invention, the flux control is used for interruption-free change from generator operating mode to motor operating mode and vice versa.

In connection therewith, it is an advantage if the resultant flux in the machine is:

$$\Phi = \Phi_1 + \Phi_2$$

where Φ_1 is the rotating flux on the stator side of the machine and Φ_2 is the flux generated by the rotor current, whereby

$$\Phi_1 = \Phi_{1magn} + \Phi_{1stator}$$

where $\Phi_{1stator}$ is the rotating flux generated by the current in the ordinary winding, whereby the speed of rotation on $\Phi_{1stator}$ is dependent on the frequency of the network and the number of pole pairs in the machine, and Φ_{1magn} is the rotating flux generated by the current in the extra winding, which flux is controllable with respect to phase position as well as amplitude and frequency relative to the flux vector of the ordinary winding.

An additional advantage in connection therewith is obtained if the vectorially created flux in the machine is controlled with the aid of the relative phase position as well as the relative amplitude value between the active and reactive current values of the ordinary winding (54) and the extra winding (56).

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be explained in greater detail by the following description of preferred embodiments of the invention with reference to the accompanying drawings.

Figure 1 is a cross-section view of a high-voltage cable;

Figure 2 is a diagram which shows a system according to the present invention for adaptation/optimization of the speed of a rotating electric machine included in the system;

Figures 3a and 3b are schematic figures which more clearly show the solution on principle for the system shown in Figure 2;

Figures 4a and 4b are schematic figures which for the purpose of clarification show, respectively, the rotating fluxes and the electromotive force (EMF) induced in the rotor part in the system shown in Figure 2;

Figures 5a, 5b and 5c are three diagrams which illustrate the principle of control/change of the speed of rotation for the resultant flux in the machine in the system shown in Figure 2; and

Figure 6 is a flow diagram of the method according to the present invention for speed control of a rotating electric machine.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows a cross-section view of a high-voltage cable 10 which is traditionally used for transmission of electric power. The high-voltage cable 10 shown may, for ex-

ample, be a standard XLPE cable 145 kV but without a sheath of screen. The high-voltage cable 10 has an electric conductor, which may have one or more strands 12 of circular cross section of, for example, copper (Cu). These strands 12 are arranged in the centre of the high-voltage cable 10. Around the strands 12 there is a first semiconducting layer 14. Around the first semiconducting layer 14 there is an insulating layer 16, for example XLPE insulation. Around the insulating layer 16 there is a second semiconducting layer 18. In the high-voltage cable 10 shown, the three layers 14, 16, 18 are designed so as to adhere to one another also when the cable 10 is bent. The shown cable 10 is flexible and this property is retained in the cable 10 during its service life.

Figure 2 shows a diagram of a system according to the present invention for adaptation/optimization of the speed of a rotating electric machine included in the system. The system 20 includes a rotating electric machine 22, which is directly connected to a distribution or transmission network 24. The rotating electric machine 24 has at least two windings, wherein each winding in a first embodiment of the present invention contains at least one conductor, a first semiconducting layer arranged surrounding the conductor, an insulating layer arranged surrounding the first semiconducting layer, and a second semiconducting layer arranged surrounding the insulating layer. According to a second embodiment of the system 20 according to the present invention, the windings are each formed from the high-voltage cable 10 shown in Figure 1. The system 20 additionally has a member 26 which generates the resultant stator and air gap flux of the machine in operation, which flux is composed of at least two vectorial quantities. In addition, the system 20 contains magnetization equipment 28, connected to the rotating electric machine 22, which in the shown example is in the form of a first frequency converter 28. Connected to the rotating electric machine 22 is an auxiliary feeder 30. In addition, the system 20 has a transformer 32 for voltage adaptation, connected to the first frequency converter 28 and the auxiliary feeder 30. The transformer 32, in its turn, is connected to a distribution busbar 36 via a first circuit breaker 34. In addition, the system 20 has a second frequency converter 38 for auxiliary power generation, which second frequency converter 38 is connected, on the one hand, to the transformer 32 and, on the other hand, to the distribution busbar 36 via a second circuit breaker 40.

Figures 3a and 3b schematically show the solution on principle for the system 20 shown in Figure 2. Figure 3a shows the rotor 50 and the stator 52, respectively, of the ro-

tating electric machine 22. The stator 52 is provided in traditional manner with a three-phase winding 54, also called ordinary winding 54 or main winding 54. In addition, the stator 52 is provided with an extra winding 56. When the rotating electric machine 22 is in operation, a rotating flux Φ_1, among other things, is generated on the stator side, which flux Φ_1 rotates in the direction of the dotted arrow. Figure 3b shows a part of the system 20 shown in Figure 2 which is of importance to the present invention. Again, the main winding 54 (three-phase) and the extra winding 56 (three-phase) of the stator are shown, the extra winding 56 being connected to the first frequency converter 28. In addition, the stator winding 58 (three-phase) of the auxiliary feeder 30 (cf. Fig. 2) is shown, which is also connected to the first frequency converter 28. The rotating electric machine 22 (cf. Fig. 2) additionally includes an asynchronous rotor 60 for the main winding 54 and the extra winding 56 of the stator. In addition, Figure 3b shows a permanent-magnet rotor 62 included in the auxiliary feeder 30 (cf. Fig. 2). The permanent-magnet rotor 62 is connected to the asynchronous rotor 60 so that these rotate together. The system 20 may be used for adaptation/optimization of the speed of a rotating electric machine 22 included in the system 20. This is achieved by composing the rotating flux Φ_1 on the stator side 52 (cf. Fig. 3) from at least two flux vectors. One flux vector is generated in traditional manner via the main winding 54 of the stator 52 and one flux vector is generated via the extra winding 56 of the stator 52 and the first frequency converter 28. By controlling the flux vector, generated via the extra winding 56 and the first frequency converter 28, with respect to phase position as well as amplitude and frequency relative to the flux vector generated via the main winding 54, the angular velocity of the total flux vector may rotate both supersynchronously and subsynchronously related to the flux vector generated via the main winding.

Figures 4a and 4b schematically show the rotating fluxes and the EMF induced in the rotor part, respectively, in the system shown in Figure 2. Figure 4a again shows parts of the rotating electric machine 22 (cf. Fig. 2) in the form of the rotor 50 and the stator 52. As is also clear from Figure 3a, the stator 52 is provided with a main winding 54 and an extra winding 56. The rotor 50 rotates in the direction of the arrow A. The rotating total flux Φ_1 of the stator 52 rotates in the direction of the arrow B with the speed $n_{\Phi 1}$. The total generated flux for the machine 22 in operation is

$$\Phi = \Phi_1 + \Phi_2$$

where Φ_1 is the rotating flux on the stator side, and Φ_2 is the flux generated by the rotor current. The rotating flux Φ_1 on the stator side may be expressed as follows

$$\Phi_1 = \Phi_{1magn} + \Phi_{1stator}$$

where $\Phi_{1stator}$ is the rotating flux generated by the current in the main winding 54, and Φ_{1magn} is rotating and controllable flux. Φ_{1magn} is generated via the extra winding 56 of the stator 52 and the first frequency converter 28. Figure 4b schematically shows the rotor 50. The rotating air gap flux induces a winding EMF, e_{rotor}, in the rotor winding. The rotor current, I_{rotor}, driven by the EMF e_{rotor} gives rise to a torque Mv. The winding EMF e_{rotor} may be expressed as

$$e_{rotor} = k1 \times \Phi_1 \times (n_{rotor} - n_{\Phi 1})$$

The torque may be expressed as

$$Mv = k2 \times \Phi_1 \times I_{rotor}$$

where k1, k2 are constants, n_{rotor} is the speed of the rotor 50, which may be changed and adapted for optimization of, for example, the efficiency of the turbine, and $n_{\Phi 1}$ is the speed of the rotating flux Φ_1 on the stator side, whereby the speed $n_{\Phi 1}$ may be changed and adapted for slip optimization.

Figures 5a, 5b and 5c show three different diagrams which illustrate the principle of control/change of the speed of rotation for the resultant flux Φ_1 on the stator side in the machine 22 in the system 20 shown in Figure 2. Figure 5a shows how $\Phi_{1stator}$ varies with the time t. The speed of rotation of $\Phi_{1stator}$ depends on the frequency of the network (cf. Fig. 2) and the number of pole pairs in the rotating electric machine 22. Figure 5b shows how Φ_{1magn} varies with the time t. The amplitude, frequency and phase position of Φ_{1magn} are determined with respect to the desired speed of rotation of Φ_1. Figure 5c shows how the resultant rotating flux Φ_1 in the stator 52 varies with the time t.

Figure 6 shows a flow diagram of the method according to the present invention for speed control of a rotating electric machine. The method according to the present invention includes a number of steps which will be described below. The flow diagram starts at block 70. The next step, at block 72, includes starting and connecting the rotating electric machine 22 to the network (cf. Fig. 2). Thereafter, at block 74, at least two vectorial quantities are generated, which constitute the resultant stator and air gap flux of the machine in operation. Provided that there are two vectorial quantities, one flux vector $\Phi_{1stator}$ is

generated via the main winding 54 of the stator 52, and one flux vector Φ_{1magn} is generated via the extra winding 56 of the stator 52 and the first frequency converter 28. Thereafter, at block 76, it is inquired whether the speed of the machine is suitable. If the question is answered in the affirmative, block 76 is reiterated. On the other hand, if the answer is negative, the method continues to block 78. In block 78, the step of controlling at least one of the vectorial fluxes with respect to phase position as well as amplitude and frequency (speed of rotation) relative to the flux generated and rotated by the connecting network is carried out. This control implies that the machine has the desired/appropriate speed. Thereafter, at block 80, it is inquired whether the machine is to be in operation. If the question is answered in the affirmative, block 76 is reiterated. On the other hand, if the answer is negative, the method continues to block 82. At block 82, the operation of the machine is stopped. At block 84, the method is terminated.

The invention is not limited to the embodiments shown but several modifications are feasible within the scope of the inventive concept. Thus adaptation of the slip frequency may take place both during motor and generator operation and by suitable dimensioning of the frequency converter equipment, all operating modes may, in principle, be met.

In addition, the principle may be applied to rapid, interruption-free change from motor operation to generator operation in, for example, industrial applications.

Further, the principle may be applied to reduction/elimination of the harmonic content in the stator voltage of a machine. The principle may be applied to both synchronous and asynchronous machines.

In addition, the frequency converter equipment and the extra winding of the stator may be used both when starting the machine upon start-up and when braking the machine upon shutdown.

Further, the angular velocity of the flux vector generated via the extra winding is controllable via the stationary frequency converter equipment and hence an optimum operating position for adaptation to a changed turbine speed caused by changed net head may always occur.

In addition, the vectorially created flux in the machine may be controlled with the aid of the relative phase position as well as the relative amplitude position between the active and reactive current values of the ordinary winding and the extra winding.

The invention is not limited to the embodiments shown, but several variants are feasible within the scope of the appended claims.

CLAIMS

1. A system (20) for adaptation/optimization of the speed of a rotating electric machine (22) included in the system (20), which machine (22) is intended to be directly connected to a distribution or transmission network (24) and comprising at least two electric windings, characterized in that the winding each comprises at least one electric conductor, a first semiconducting layer (14) arranged surrounding the conductor, an insulating layer (16) arranged surrounding the first semiconducting layer (14), and a second semiconducting layer (18) arranged surrounding the insulating layer (16), and that the system (20) comprises mechanisms(26) which generate the resultant stator and air gap flux of the machine (22) during operation, which flux is composed of at least two vectorial quantities.

2. A system (20) according to claim 1, characterized in that the potential of the first semiconducting layer (14) is essentially equal to the potential of the conductor.

3. A system (20) according to claim 1 or 2, characterized in that the second semiconducting layer (18) is adapted to form essentially one equipotential surface, surrounding the conductor.

4. A system (20) according to claim 3, characterized in that the second semiconducting layer (18) is connected to a predetermined potential.

5. A system (20) according to claim 4, characterized in that said predetermined potential is ground potential.

6. A system (20) according to any of the preceding claims, characterized in that at least two adjacent layers of the windings of the machine have essentially identical coefficients of thermal expansion.

7. A system (20) according to any of the preceding claims, characterized in that the conductor comprises a number of strands (12), at least some of which are in electric contact with one another.

8. A system (20) according to any of the preceding claims, characterized in that each of said three layers is secured to adjacent layers along essentially the whole contact surface.

9. A system (20) for adaptation/optimization of the speed of a rotating electric machine (22) included in the system (20), which machine is intended to be directly connected to a distribution or transmission network (24) and comprising at least two electric windings, characterized in that the windings are each formed from a high-voltage cable (10) comprising one or more current-carrying conductors, whereby each conductor exhibits a number of strands (12), a first semiconducting layer (14) arranged around each conductor, an insulating layer (16) of solid insulating material arranged around said first semiconducting layer (14), and a second semiconducting layer (18) arranged around the insulating layer (16), and that the system (20) comprises means (26) which generate the resultant stator and air gap flux of the machine (22) in operation, which flux is composed of at least two vectorial quantities.

10. A system (20) according to any of the preceding claims, characterized in that the insulating conductor or high-voltage cable (10) is flexible.

11. A system (20) according to claim 10, characterized in that the layers are arranged to adhere to one another also when the insulated conductor or high-voltage cable (10) is bent.

12. A system (20) according to any of the preceding claims, characterized in that the flux-generating member (26) comprises an extra winding (56), arranged on the stator (52) of the machine (22), and magnetization equipment (28) connected to the machine (22), whereby one flux vector is generated via the extra winding (56) and the magnetization equipment (28) and one flux vector is generated via the ordinary winding (54) of the machine (22).

13. A system (20) according to claim 12, characterized in that the magnetization equipment (28) is in the form of a first frequency converter (28).

14. A system (20) according to claim 13, characterized in that the system (20), in addition, comprises an auxiliary feeder (30) connected to the first frequency converter (28) and the machine (22).

15. A system (20) according to claim 14, characterized in that the machine (22) comprises an asynchronous rotor (60) and that the auxiliary feeder (30) comprises a stator winding (58) and a permanent-magnet rotor (62) connected to the asynchronous rotor (60).

16. A system (20) according to any of claim 14 or 15, characterized in that the system (20), in addition, comprises a transformer (32) connected to the first frequency converter (28) and the auxiliary feeder (30), said transformer being connected to a distribution busbar (36) via a first circuit breaker (34), and a second frequency converter (38) which is connected to the transformer (32) and which is connected to the distribution busbar (36) via a second circuit breaker (40).

17. A system (20) according to claim 1, characterized in that the windings are flexible and in that said layers make contact with one another.

18. A system (20) according to claim 17, characterized in that said layers are of a material with such elasticity and such a relation between the coefficients of thermal expansion of the materials that the volume changes of the layers, caused by temperature variations during operation, are capable of being absorbed by the elasticity of the materials such that the layers retain their contact with one another at the temperature variations which occur during operation.

19. A system (20) according to claim 18, characterized in that the materials in said layers have a high elasticity.

20. A system (20) according to claim 18, characterized in that each semiconducting layer constitutes essentially an equipotential surface.

21. A method for speed control of a rotating electric machine (22), which machine (22) is intended to be directly connected to a distribution or transmission network (24) and comprising at least two electric windings, each winding comprising at least one electric conductor, a first semiconducting layer (14) arranged surrounding the conductor, an insulating layer (16) arranged surrounding the first semiconducting layer (14), and a second semiconducting layer (18) arranged surrounding the insulating layer (16), which method comprises the following step:

- generating at least two vectorial quantities which constitute the resultant stator and air gap flux of the machine (22) during operation.

22. A method for speed control of a rotating electric machine (22), which machine (22) is intended to be directly connected to a distribution or transmission network (24) and comprising at least two electric windings, each winding being formed of a high-voltage cable (10) comprising one or more current-carrying conductors, whereby each conductor exhibits a number of strands, a first semiconducting layer (14) arranged around each conductor, an insulating layer (16) of solid insulating material arranged around said first semiconducting layer (14), and a second semiconducting layer (18) arranged around the insulating layer (16), which method comprises the following step:

- generating at least two vectorial quantities which constitute the resultant stator and air gap flux of the machine (22) during operation.

23. A method according to any of claim 21 or 22, which method is characterized by the following additional step:

- controlling at least one of the vectorial fluxes with respect to phase position as well as amplitude and speed of rotation relative to the flux generated and rotated by the connecting network (24).

24. A method according to claim 23, characterized by the following steps:

- generating a flux vector via an extra winding (56), mounted on the machine (22), and magnetization equipment (28) connected to the machine (22), and
- generating a flux vector via the ordinary winding (54) of the machine (22).

25. A method according to any of claim 23 or 24, characterized in that the rotating electric machine (22), in addition, comprises an asynchronous rotor (60), whereby the flux control is used for speed control of the machine (22) in generator operating mode.

26. A method according to any of claim 23 or 24, characterized in that the rotating electric machine (22), in addition, comprises an asynchronous rotor (60), whereby the flux control is used for speed control of the machine (22) in motor operating mode.

27. A method according to any of claim 23 or 24, characterized in that the flux control is used for damping the harmonic content of the stator voltage in the ordinary winding (54) of the machine (22).

28. A method according to claim 24, characterized in that the reactive magnetization current of the machine (22) is injected via the extra winding (56), whereby it is possible to control the voltage of the machine (22) on the ordinary winding (54) of the machine (22) for both a non-mains-connected and a mains-connected machine (22).

29. A method according to claim 25, characterized in that the rotating electric machine (22), in addition, comprises a permanent-magnet rotor (62), connected to the asynchronous rotor (60), for generating magnetization current and other auxiliary power.

30. A method according to any of claim 23 or 24, characterized in that the flux control is used for interruption-free change from generator operating mode to motor operating mode and vice versa.

31. A method according to any of claims 24-30, characterized in that the resultant flux in the machine (22) is

$$\Phi = \Phi_1 + \Phi_2 \quad \text{(Komplettera med vektorstreck !)}$$

where Φ_1 is the rotating flux on the stator side of the machine and Φ_2 is the flux generated by the rotor current, whereby

$$\Phi_1 = \Phi_{1\text{magn}} + \Phi_{1\text{stator}} \quad \text{(Komplettera med vektorstreck !)}$$

where $\Phi_{1\text{stator}}$ is the rotating flux generated by the current in the ordinary winding

(54), whereby the speed of rotation on $\Phi_{1stator}$ is dependent on the frequency of the network and the number of pole pairs in the machine (22), and Φ_{1magn} is the rotating flux generated by the current in the extra winding (56), which flux is controllable with respect to phase position as well as amplitude and frequency relative to the flux vector of the ordinary winding (54).

32. A method according to claim 24, characterized in that the vectorially created flux in the machine (22) is controlled with the aid of the relative phase position as well as the relative amplitude value between the active and reactive current values of the ordinary winding (54) and the extra winding (56).

ABSTRACT OF THE DISCLOSURE

The invention relates to a system for adaptation/optimization of the speed of a rotating electric machine included in the system, wherein the machine is intended to be directly connected to a distribution or transmission network. The machine has at least two electric windings, each of which is formed from at least one electric conductor, a first semiconducting layer arranged surrounding the conductor, an insulating layer arranged surrounding the first semiconducting layer, and a second semiconducting layer arranged surrounding the insulating layer . In addition, the system is configured to generate a resultant stator and air gap flux of the machine during operation, wherein the flux is composed of at least two vectorial quantities.

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

IN RE APPLICATION OF: Erland SORENSEN

SERIAL NUMBER: 09/554,905

FILED: 22 MAY 2000

FOR: A METHOD AND A SYSTEM FOR SPEED CONTROL OF A ROTATING ELECTRICAL MACHINE WITH FLUX COMPOSED OF TWO QUANTITIES

SUBMISSION OF DECLARATION UNDER 37 CFR 1.495

ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, D.C. 20231

SIR:

In accordance with the provisions of 37 CFR 1.495 Applicants submits herewith a Rule 63 Declaration.

The required fee was paid at the time of filing the application.

In light of the foregoing, this application has now met all the requirements under 35 U.S.C. 371 for entering the national stage. An early receipt of the Notification of Acceptance is hereby earnestly solicited.

Respectfully submitted,

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Declaration, Power Of Attorney and Petition

WE (I) the undersigned inventor(s), hereby declare(s) that:

My residence, post office address and citizenship are as stated below next to my name,

We (I) believe that we are (I am) the original, first, and joint (sole) inventor(s) of the subject matter which is claimed and for which a patent is sought on the invention entitled

A METHOD AND A SYSTEM FOR SPEED CONTROL OF A ROTATING ELECTRICAL MACHINE WITH FLUX COMPOSED OF TWO QUANTITIES

the specification of which

☐ is attached hereto.

☒ was filed on May 22, 2000 as

Application Serial No. ______

and amended on ______.

☑ was filed as PCT international application

Number PCT/SE98/02161

on November 27, 1998,

and was amended under PCT Article 19

on ______ (if applicable).

We (I) hereby state that we (I) have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

We (I) acknowledge the duty to disclose information known to be material to the patentability of this application as defined in Section 1.56 of Title 37 Code of Federal Regulations.

We (I) hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed. Prior Foreign Application(s)

Application No.	Country	Day/Month/Year	Priority Claimed
9704375-6	SWEDEN	27 NOVEMBER 1997	☑ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

We (I) hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

(Application Number)	(Filing Date)
(Application Number)	(Filing Date)

We (I) hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

Application Serial No.	**Filing Date**	**Status (pending, patented, abandoned)**
PCT/SE98/02161	27 NOVEMBER 1998	

And we (I) hereby appoint: Norman F. Oblon, Reg. No. 24,618; Marvin J. Spivak, Reg. No. 24,913; C. Irvin McClelland, Reg. No. 21,124; Gregory J. Maier, Reg. No. 25,599; Arthur I. Neustadt, Reg. No. 24,854; Richard D. Kelly, Reg. No. 27,757; James D. Hamilton, Reg. No. 28,421; Eckhard H. Kuesters, Reg. No. 28,870; Robert T. Pous, Reg. No. 29,099; Charles L. Gholz, Reg. No. 26,395; William E. Beaumont, Reg. No. 30,996; Jean-Paul Lavalleye, Reg. No. 31,451; Stephen G. Baxter, Reg. No. 32,884; Richard L. Treanor, Reg. No. 36,379; Steven P. Weihrouch, Reg. No. 32,829; John T. Goolkasian, Reg. No. 26,142; Richard L. Chinn, Reg. No. 34,305; Steven E. Lipman, Reg. No. 30,011; Carl E. Schlier, Reg. No. 34,426; James J. Kulbaski, Reg. No. 34,648; Richard A. Neifeld, Reg. No. 35,299; J. Derek Mason, Reg. No. 35,270; Surinder Sachar, Reg. No. 34,423; Christina M. Gadiano, Reg. No. 37,628; Jeffrey B. McIntyre, Reg. No. 36,867; William T. Enos, Reg. No. 33,128; Michael E. McCabe, Jr., Reg. No. 37,182; Bradley D. Lytle, Reg. No. 40,073; and Michael R. Casey, Reg. No. 40,294; our (my) attorneys, with full powers of substitution and revocation, to prosecute this application and to transact all business in the Patent Office connected therewith; and we (I) hereby request that all correspondence regarding this application be sent to the firm of OBLON, SPIVAK, McCLELLAND, MAIER & NEUSTADT, P.C., whose Post Office Address is: Fourth Floor, 1755 Jefferson Davis Highway, Arlington, Virginia 22202.

We (I) declare that all statements made herein of our (my) own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

1-00

Erland SORENSEN
NAME OF ~~FIRST~~ SOLE INVENTOR

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